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DIFFERENT NEUROMUSCULAR PARAMETERS INFLUENCE DYNAMIC BALANCE IN MALE AND FEMALE FOOTBALL PLAYERS

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Abstract

Purpose: To analyse the relationship between several parameters of neuromuscular performance with unilateral dynamic balance measured through the Y-Balance test, as well as to determine the possible sex-related differences.

Methods: The Y-Balance test, isokinetic (concentric and eccentric) knee flexion and extension strength, isometric hip abduction and adduction strength, lower extremity joint range of motion (ROM) (hip, knee and ankle) and core stability were assessed in male (n = 88) and female (n = 44) professional football players. A stepwise multivariate linear least square regression with backward elimination analysis was carried out to identify a group of factors that were independently associated with balance performance in both sexes.

Results: Passive hip flexion and ankle dorsiflexion with knee flexed ROM were the main factors that retained a significant association to dominant (R^2 = 23.1) and non-dominant (R^2 = 33.5) balance scores for males. For females, core stability, hip abduction isometric peak torque, passive hip abduction and ankle dorsiflexion with knee flexed ROM variables retained a significant association with balance scores for both, dominant (R^2 = 38.2) and non-dominant (R^2 = 46.9) legs.

Conclusions: Training interventions aimed at improving or maintaining unilateral dynamic balance in male football players should include, among other things, stretching exercises for the posterior chain of the lower extremity. However, females should also include exercises for strength and mobility of the hip abductors and core stability (especially in the frontal plane). This knowledge would allow clinicians and sport practitioners to develop more effective and tailored unilateral dynamic balance training interventions in male and female football players, possibly improving performance and reducing the risk of injury.

Level of evidence: Level III

Keywords: *Y-Balance, injury, strength, trunk stability, performance.*

Introduction

Unilateral dynamic balance defined as the ability of an individual to maintain the center of mass within the body´s base whilst performing single leg movement [14], is considered a fundamental ability to safely and accurately perform several explosive sport actions carried out over a single leg [29]. Consequently, unilateral dynamic balance may be considered a fundamental component of performance in the game of football, where players are required to perform repetitive and explosive unilateral movements such as sudden acceleration and deceleration tasks, rapid changes of direction, kicking, jumping and landing [6,27].

The Y-Balance test is one of the most popular tools used to measure unilateral dynamic balance [10,16,31]. The Y-Balance test has been considered a clinically efficient (field-based) test because its procedure is simple to administer, it is relatively inexpensive, portable and large numbers can be tested in a short period of time [17,20]. Furthermore, the Y-Balance test has demonstrated being sensitive enough to differentiate between different levels of competition [8,27,34] and sporting populations [6]. Likewise, this test has been used to detect unilateral dynamic balance deficits in patients with chronic ankle instability [19,24], patellofemoral pain syndrome [13] and anterior cruciate ligament deficiency [18]. Finally, poor performance and bilateral asymmetries on the Y-Balance test may be related to an increased risk for non-contact lower extremity injuries (mainly ankle sprains) [3,7,11,28].

These measurement properties may have contributed to the Y-Balance test becoming one of the most widely used tools not only to identify athletes at high risk of injury but also to guide preventive and rehabilitation programs. This increase in the Y-Balance test popularity seems to be in contrast to other more sophisticated, costly and time consuming tools (e.g.: dynamometers, force platforms, goniometry, 3D motion analysis devices) designed to measure other sport performance and injury risk factors and whose implementation in daily clinical practice or on the sports field is difficult.

Unilateral dynamic balance is a complex ability derived from the coordination and synergy between vestibular, visual and somatosensory systems [35] and hence, may be influenced, among others, by some measures of neuromuscular performance (i.e. hip and knee strength, lower extremity joint range of motion [ROM], core stability). Therefore, due to the relevance of the Y-Balance test (as a measure of unilateral dynamic balance) for sport performance and injury prevention/rehabilitation, it seems necessary to identify which measures of neuromuscular performance contribute to Y-Balance performance in order to design targeted training interventions.

Although some studies have explored the individual contribution of certain modifiable measures of neuromuscular performance on Y-Balance test in football (knee [5,23] and hip [1] strength, jumping ability [5,26], core stability [1,26] and ankle dorsiflexion [25,30] and hip flexion [30] ROMs) only one study has used professional players [5]. In addition, to the authors´ knowledge, no studies have analysed the concurrent influence of the main modifiable neuromuscular measures (hip and knee strength, core stability and lower extremity joints ROM) in the Y-Balance test performance in football players. This concurrent or multiple regression analysis assists in the diagnosis of the possible presence of multicollinearity amongst neuromuscular measures (phenomenon in which one predictor in a multiple regression model can be linearly predicted from the others with a substantial degree of accuracy) and therefore correction procedures can be applied (if it is needed) [12]. The elimination of redundant predictors from the regression model may help to select only those measures of neuromuscular performance that have an individual impact on Y-Balance test, optimizing the design of training and rehabilitation interventions.

Therefore, the main purpose of this study was to analyse the relationships between several parameters of neuromuscular performance with unilateral dynamic balance measured throughout Y-Balance test as well as to determine the possible sex-related differences in a cohort of professional football players. Based on the results reported by previous studies and the movements associated with the Y-Balance test, it was hypothesized that the hip, knee and ankle flexion ROM measures as well as the eccentric isokinetic strength of the knee flexors would have a significant impact on the performance of the test.

Materials and Methods

This was a cross sectional study that was performed during the pre-season for both male and female teams, which was at the beginning of August and September, respectively.

A total of 88 male and 79 female professional football players were contacted to take part in the current study (convenience sampling). To be included, all participants had to be free of pain at the time of the study and currently involved in football-related activities. Participants were excluded if they reported the presence of any lower extremity injury within the last month, a current upper respiratory tract infection, any bone or joint abnormalities, any uncorrected visual and vestibular problems and/or a concussion within the last three months [5]. The study was conducted during the pre-competitive phase of the year in 2013.

Before any participation, experimental procedures and potential risks were fully explained to the participants in verbal and written form, and written informed consent was obtained from participants. An Institutional Research Ethics committee approved the study protocol prior data collection (DPS.FAR.01.14), conforming to the recommendations of the Declaration of Helsinki.

Of the 79 female players contacted, all female players from two teams (n = 35) were excluded from the study because they did not complete the testing sessions due to: a) time restrictions (one team) and b) technical problems (one team). Therefore 132 professional football players (88 male and 44 female) from 6 different football teams completed this study (Table 1). All football teams were engaged in the professional Championships of the Spanish Football Federation.

Table 1: Demographic variables for the professional soccer players.

	Males (n = 88)	**Females (n = 44)**
Age (years)	25.5 ± 5.0	20.1 ± 4.2
Length (cm)	180.1 ± 6.5	161.4 ± 5.2
Body mass (kg)	75.0 ± 6.5	57.2 ± 9.7
Years playing soccer (years)	16.1 ± 4.0	8.4 ± 3.1
Weekly practice frequency (days)	6.1 ± 1.2	3.3 ± 1.4
Hours of soccer practice per week	9.8 ± 2.1	5.1 ± 1.7
Hours of soccer practice per training session	1.6 ± 0.2	1.3 ± 0.3

Values expressed as mean ± standard deviation

Testing procedure

Prior to the neuromuscular testing, all participants performed a standardised dynamic warm-up. Three to five minutes after the dynamic warm-up was carried out, participants completed 5 different testing manoeuvres: 1) unilateral dynamic balance; 2) isometric hip abduction and adduction strength; 3) lower extremity joint range of motions; 4) core stability; and 5) isokinetic knee flexion and extension strength. The order of the tests was consistent for all participants with the intention of minimizing any possible negative influence among variables (Figure 1).

TESTING PROCEDURE

Dynamic warm up

1. Unilateral dynamic balance
2. Isometric hip abduction and adduction strength
3. Lower extremity Joint range of motion
4. Core stability
5. Isokinetic knee flexion and extension strength

Figure 1: Testing procedure

Unilateral dynamic balance was measured using the Y-Balance test (Y-Balance Test™, Move2Perform, Evanville, IN) (composite score) (appendix 1) and followed the guidelines proposed by Shaffer et al. [32]. After having completed a 2 min practise of the testing procedure, players were allowed a maximum of 5 trials to obtain 3 successful trials for each reach direction (anterior, posteromedial and posterolateral). To obtain a global measure of the unilateral balance performance, the greatest distance reached in each direction were normalised (by dividing by leg length) and the averaged to establish a composite balance score [15].

Isometric hip abduction and adduction peak torque of the dominant and non-dominant limb were assessed using a portable handheld dynamometer (Nicholas Manual Muscle Tester, Lafayette Indiana Instruments) with the participant lying in a supine position on a plinth with legs extended (appendix 2), following the methods described by Thorborg et al [33]. Participants performed two practical trials (50 and 80% of the self-perceived isometric maximal voluntary contraction) and then five trials of 5s isometric maximal voluntary contraction for each hip movement. The best trial was used for the subsequent statistical analyses.

Likewise, passive hip flexion with knee flexed (appendix 3a) and extended (appendix 3b), extension (appendix 3c), abduction (appendix 3d), external (appendix 3e) and internal (appendix 3f) rotation; knee flexion (appendix 3g); and ankle dorsiflexion with knee flexed (appendix 3h) and extended (appendix 3i) ROMs of the dominant and non-dominant limb were assessed following the methods previously described [9]. Participants were instructed to perform, in a randomised order, two maximal trials of each ROM test for each extremity. The best score for each test was used in the subsequent analyses.

An unstable sitting protocol was used to assess participant's core stability, determined as the ability to control trunk posture and motion while sitting (appendix 4), following the methods previously described by Barbado et al. [4]. Briefly, after a familiarization / practice period (2 min), participants performed different static and dynamic tasks while sitting on an unstable seat. All tasks were performed twice. The duration of each trial was 70s and the rest period between trials was 1 min. The mean radial error was used as a global measure to quantify the trunk/core performance during the trials.

Finally, isokinetic concentric and eccentric torques during knee extension and flexion actions in both limbs were determined (Biodex System-4, Biodex Corp., Shirley, NY, USA), following the methods employed by Ayala et al. [2] (appendix 5). In each of the three trials at each velocity, the peak torque was reported as the single highest torque value achieved. For each peak torque variable, the best of the 3 sets at each velocity was used for subsequent statistical analysis. When a variation >5% was found in the peak torque values between the 3 trials, the mean of the two most closely related torque values were used for the subsequent statistical analyses.

For the sake of brevity and the lack of space, the procedure of the 5 testing manoeuvres used in this study have not been described here. Instead, we have only specified the names and refer the reader to their original sources. In addition, table 2 summarizes the list of variables recorded from each assessment manoeuvre and also shows the abbreviations that have been used within the manuscript.

Each of the 6 testers who took part in this study conducted the same tests throughout all the testing sessions. All testers had more than 4 years of experience in using the neuromuscular assessments.

Statistical analysis

The distributions of raw data sets were checked using the Kolomogorov-Smirnov test and demonstrated that all data were normally distributed ($p > 0.05$). Descriptive statistics including means and standard deviations were calculated for each variable. Dependent t tests were used to test for differences between the scores of the dominant and non-dominant limbs for the measures obtained from the unilateral testing manoeuvres (unilateral dynamic balance; isometric hip abduction and adduction strength; lower extremity joint range of motions; and isokinetic knee flexion and extension strength). Independent t tests were applied to examine sex differences in the neuromuscular parameters.

Pearson's correlation moments (r) were used to assess the relationship between trunk stability, range of motion, hip and knee strength and Y-Balance test performance. Subsequently, in order to identify a group of factors that were independently associated with balance performance, all potential factors that showed significant associations with the composite normalized reach score of Y-Balance test and met the assumptions of normality, linearity, homoscedasticity, and presence of multicollinearity were entered into a stepwise multivariate linear least square regression with backward elimination ($p \leq 0.1$). Normality, linearity, and homoscedasticity assumptions were confirmed via observation of both the normality probability plots of the regression standardized residual plots and the standardized residual versus the regression standardized predicted value scatterplots. Multicollinearity was defined as a Pearson product moment correlation coefficient between 2 variables of equal to or greater than 0.7, therefore only those parameters which showed correlations lower than 0.7 was used for further analysis [12]. The strength of the predictive ability of identified factors was determined with unstandardized regression coefficients (β), while the predictive power of each final model was given by calculation of the percentage of explained variance (R^2). Both, correlational and multiple regression analysis were performed for males and females independently. Potential confounding variables (age, mass, stature, playing experience and competitive level [self-reported through a standardised ad hoc questionnaire]) were included in the regression model. Significance level was set at a level of $p < 0.05$. All data were analysed using the Statistical Package for Social Sciences (version 22 for Windows, SPSS Inc, Chicago, IL, USA).

Sample size estimation

The sampling software package GPower 3.1 (sample size estimation, contrast of hypothesis, comparing groups means, independent groups) was used to calculate (a priori) the sample size needed to detect meaningful results through a linear multiple regression analysis. An alpha level of 0.05, a desired power of 0.9, an effect size of 0.02 (weak) and 5 predictors were introduced in the sample size estimation analysis.

The analysis indicated that a minimal sample size of 45 participants would be required for each group (males and females). Considering the possible level of dropout in this type of intervention (around 25%) and that typically 18-22 players comprise a typical professional football team, players recruited from 4 different teams for each group would be needed to ensure an appropriate final sample size.

Results

Descriptive statistics (mean ± standard deviation) for each variable are displayed in table 2. Table 2 also displays those variables that showed significant differences between legs and sexes.

Passive hip flexion with knee flexed and ankle dorsiflexion with knee flexed ROMs were the main factors that demonstrated a significant and positive association with dominant and non-dominant composite balance scores for males (Table 3). The model derived for the non-dominant limb composite balance score showed a greater degree of explained variance (33.5%) than the dominant limb (23.1%).

For females (table 3), core stability (medial-lateral displacements with feedback) and isometric hip abduction strength demonstrated a significant and positive association with balance for both dominant and non-dominant limbs. Passive hip abduction and ankle dorsiflexion with knee flexed ROMs also showed a significant positive association with balance for the dominant and non-dominant limb respectively. Similar to males, the model derived for the non-dominant limb composite balance score explained more of the variance (46.9%) than the dominant limb (38.2%).

Table 2: Neuromuscular performance values of the male and female professional soccer players (mean ± SD).

Variable	Males (n = 88)		Females (n = 44)	
	Dominant leg	**Non-dominant leg**	**Dominant leg**	**Non-dominant leg**
Unilateral dynamic balance				
Composite	88.3 ± 7.8	88.7 ± 7.1	86.8 ± 6.4	87.7 ± 5.6
*Isokinetic strength (N*m/kg)*				
Concentric KF*				
▪ PT_{60}	1.2 ± 0.2^{T}	1.1 ± 0.2	0.8 ± 0.2	0.8 ± 0.2
▪ PT_{180}	0.9 ± 0.2	0.9 ± 0.2	0.6 ± 0.2	0.6 ± 0.2
▪ PT_{240}	0.9 ± 0.2^{T}	0.9 ± 0.2	0.6 ± 0.2	0.6 ± 0.2
▪ PT_{300}	0.9 ± 0.2^{T}	0.8 ± 0.2	0.6 ± 0.2	0.6 ± 0.2
Concentric KE*				
▪ PT_{60}	2.5 ± 0.5^{T}	2.4 ± 0.4	1.7 ± 0.4	1.7 ± 0.4
▪ PT_{180}	1.7 ± 0.3	1.7 ± 0.3	1.1 ± 0.3	1.1 ± 0.4
▪ PT_{240}	1.5 ± 0.3	1.5 ± 0.3	1 ± 0.3	1 ± 0.3
▪ PT_{300}	1.4 ± 0.3	1.3 ± 0.3	1 ± 0.3	0.9 ± 0.3
Eccentric KF				
▪ PT_{30}	2.7 ± 0.8^{T}	2.6 ± 0.8	2.6 ± 0.6	2.5 ± 0.6
▪ PT_{60}	2.8 ± 0.7^{T}	2.6 ± 0.8	2.5 ± 0.6	2.6 ± 0.6
▪ PT_{180}	2.5 ± 0.7	2.4 ± 0.8	2.4 ± 0.6	2.4 ± 0.6
Eccentric KE				
▪ PT_{30}	1.2 ± 0.3^{T}	1.1 ± 0.3*	1.1 ± 0.3^{T}	1 ± 0.2
▪ PT_{60}	1.2 ± 0.3*^{T}	1.1 ± 0.3*	1.1 ± 0.3*^{T}	1 ± 0.2
▪ PT_{180}	1.2 ± 0.3^{T}	1.1 ± 0.3*	1.1 ± 0.3	1 ± 0.3

Isometric hip strength (N/kg)				
PT_{HABD}*	2.7 ± 0.4	2.8 ± 0.4	2.4 ± 0.4	2.4 ± 0.4
PT_{HADD}*	2.7 ± 0.5	2.7 ± 0.5	2.3 ± 0.4	2.3 ± 0.4
Core stability (mm)				
CS_{NF}	6.1 ± 2.2*		4.3 ± 1.7	
CS_{WF}	5.3 ± 1.4		5.5 ± 2.4	
CS_{ML}	8.3 ± 2.0*		7.2 ± 2.5	
CS_{AP}	8.3 ± 1.7*		7.2 ± 2.1	
CS_{CD}	10.8 ± 3.0*		9.2 ± 3.7	
Lower extremity joint ROM (º)				
PHF_{KE}	80.3 ± 10.7	80.9 ± 10.9	81.6 ± 12.6	81.7 ± 12.5
PHF_{KF}	146.6 ± 8.4*^{T}	147.9 ± 7.6*	153.8 ± 8.5	154.5 ± 7.1
PHA	63.9 ± 8.9^{T}	61.5 ± 8.7	63.6 ± 6.9	61.9 ± 7.8
PHER	50.0 ± 9.3*	50.4 ± 9.6*	61.6 ± 6.9	61.2 ± 8.2
PHIR	47.4 ± 8.3*^{T}	45.7 ± 7.7*	56.1 ± 9.1	55.1 ± 8.2
PHE	9.6 ± 8.7*	10.4 ± 8.4*	15.6 ± 5.7	15.6 ± 5.4
PKF	127.6 ± 13.3^{T}	125.5 ± 13.6	130.0 ± 13.8^{T}	129.4 ± 13.6
ADF_{KF}	37.2 ± 6.6*^{T}	38.2 ± 5.9	39.9 ± 4.9^{T}	38.1 ± 5.5
ADF_{KE}	36.2 ± 5.6	36.5 ± 5.6*	36.0 ± 4.9^{T}	32.7 ± 4.4

*: significant differences between sexes ($p<0.05$); ^{T}: significant differences between legs ($p<0.05$). PT: peak torque; KF: knee flexion; KE: knee extension; N: newton; m: metres; kg: kilograms; mm: millimetres; HABD: hip abduction; HADD: hip adduction; CS_{NF}: unstable sitting without feedback; CS_{WF}: unstable sitting with feedback; CS_{ML}: unstable sitting while performing medial-lateral displacements with feedback; CS_{AP}: unstable sitting while performing anterior-posterior displacements with feedback; CS_{CD}: unstable sitting while performing circular displacements with feedback; ROM: range of motion; PHF_{KF}: passive hip flexion with knee flexed ROM; PHF_{KE}: passive hip flexion with knee extended ROM; PHA: passive hip abduction ROM; PHIR = passive hip internal rotation ROM; PHER: passive hip external rotation ROM; PHE: passive hip extension ROM; PKF: passive knee flexion ROM; ADF_{KE}: ankle dorsiflexion with knee extended ROM; ADF_{KF}: ankle dorsiflexion with knee flexed ROM.

Table 3: Backward multivariate linear regression analysis. Significant predictor variables ($p \leq 0.10$) for the composite normalized reach scores obtained from Y-Balance test.

	Explained variance (R^2)				Regression equation
	Model	**1st Variable**	**2nd Variable**	**3rd Variable**	
MALES					
Dominant	*23.1 %*	PHF_{KF} 14.6%	ADF_{KF} 8.5%		$Y = 33.47 + 0.29*PHF_{KF} + 0.32*ADF_{KF}$
Non-Dominant	*33.5%*	ADF_{KF} 20.7%	PHF_{KF} 12.8%		$Y = 24.46 + 0.43* ADF_{KF} + 0.32* PHF_{KF}$
FEMALES					
Dominant	38.2%	PHA 22.0%	PT_{HABD} 11.4%	CS_{ML} 4.8%	$Y = 61.63 + 0.31*PHA + 4.26* PT_{HABD} - 0.63* CS_{ML}$
Non-Dominant	46.9%	CS_{ML} 31.1%	PT_{HABD} 10.4%	ADF_{KF} 5.4%	$Y = 71.08 - 0.81*CS_{ML} + 5.47* PT_{HABD} + 0.24*ADF_{KF}$

Y = composite normalized reach scores obtained from Y-Balance test.

PT_{HABD} (N/kg) = peak of force during hip abduction exertions.

CS_{ML} (mm) = core stability during unstable sitting while performing medial-lateral displacements with feedback.

PHA (º) = passive hip abduction range of motion; PHF_{KF} (º) = passive hip flexion with knee flexed range of motion; ADF_{KF} (º) = ankle dorsiflexion with knee flexed range of motion.

Overall both derived models for balance of the dominant and non-dominant limb displayed greater predictive power for the females compared with the males.

Discussion

The most important finding of the current study is that despite the fact that male and female professional football players performed similarly on the Y-Balance test, the overall balance score was influenced by different predictors.

For males, the results of the current study showed that only passive hip flexion with knee flexed and ankle dorsiflexion with knee flexed ROMs were significant predictors in determining a meaningful proportion of the R^2 for the Y-Balance test (composite score) for both dominant (passive hip flexion with knee flexed ROM = 14.6%; ankle dorsiflexion with knee flexed ROM = 8.5%) and non-dominant (passive hip flexion with knee flexed ROM = 19.8%; ankle dorsiflexion with knee flexed ROM = 12.5%) legs.

These results are in agreement with the findings reported by previous studies [25,30], although not all [16], who found that ankle dorsiflexion with knee flexed ROM accounted for an estimated ≈ 20% of the variance in Y-Balance test in physically active adults. This finding may support the hypothesis that altered ankle dorsiflexion with knee flexed ROM might influence unilateral dynamic balance via mechanical (due to ligamentous insufficiency) and/or functional instability (altered neuromuscular control) [21].

Regarding passive hip flexion with knee flexed, Robinson & Gribble [30] found that hip flexion ROM of the stance leg was a significant predictor for the reach distances during the Y-Balance test. From a theoretical point of view, football players with limited hip flexion ROM on the stance leg (<70º [value suggested according to the authors´ extensive experience]) might show a sub-optimal unilateral dynamic balance while performing explosive actions (i.e. kicking and changes of direction) due to less anterior displacement of their center of mass, which may increase the likelihood of losing stability. The lack of statistically significant correlations among the others passive hip and knee ROMs and unilateral dynamic balance has been previously supported by Overmoyer et al. [25] but using active manoeuvres.

The results found in this study for the isokinetic strength of the knee are in concordance with the findings reported by Booysen, Gradidge & Watson [5] and Lockie et al. [23], who did not show any relationship between the isokinetic strength of the knee flexors and extensors and the Y-Balance test score in professional football players and team-sport athletes respectively.

The current findings regarding isometric strength of the hip adductors and abductors and the core stability variables cannot be compared with previous studies because this appears to be the first that has explored these neuromuscular parameters in relation to unilateral dynamic balance. Similar to the findings for isokinetic strength of the knee, the isometric strength of the hip adductors and abductors does not appear to be a major contributing factor to good dynamic balance of these professional male footballers who show high scores. Likewise, it is possible that the unstable sitting methodology used to measure core stability is not movement-specific enough to find any significant correlation with performance in closed-chain, functional testing in this cohort of highly trained male footballers.

For females, the findings of the current study demonstrate that passive hip abduction ROM (22%), isometric hip abduction strength (11.4%) and core stability (medial-lateral displacements with feedback) (4.8%) are all significant predictors in Y-Balance test for the dominant leg, whereas the core stability (medial-lateral displacements with feedback) (31.1%), isometric hip abduction strength (10.4%) and ankle dorsiflexion with knee flexed ROM (5.4%) are significant predictors for the non-dominant leg.

Similar results to those found in the current study for passive hip abduction and ankle dorsiflexion with knee flexed ROM measures have been reported in previous studies [25,30] indicating that individuals with higher scores in such variables achieved better performance in the Y-Balance test and therefore, demonstrate superior unilateral dynamic balance. In particular, higher passive hip abduction ROM scores may have a positive effect on the reached distance in the posteromedial direction, which could potentially impact on the composite score of the Y-Balance test.

Previously correlations between isometric hip abduction strength and the distances achieved in the Y-Balance test have been demonstrated by Ambegaonkar et al. [1] in university lacrosse and football players (R^2 = 11.5%). The positive and significant relationship found in the current study between hip abductor strength and unilateral dynamic balance may be attributed to the role that the abductor muscles play during single leg movements [22].This is primarily as a hip stabilizer in the frontal plane, which may help to maintain a more stable position whilst the players are performing the Y-Balance test and subsequently aid in longer distances being reached.

Although core stability has been proposed as a crucial factor for Y-Balance test [22], this is the first study (to the authors´ knowledge) confirming this link in professional female football players. Deficits in core stability, especially in the frontal plane, could lead to uncontrolled upper body displacements during single leg movements, moving the center of mass of the body away from the supporting foot , which might compromise dynamic stability of the lower extremity [36].

The rest of the measures related to core stability, isokinetic strength of the knee flexors and extensors, isometric strength of the hip adductors, and ROM of the hip and knee joints showed no significant contribution to the Y-Balance test scores for the dominant and non-dominant legs.

Apart from the obvious anatomical differences, it is possible that these sex-related differences might be attributed to the fact that females had less playing experience, and lower weekly training load than males. Highly complex and intensive tasks are constantly required within the game of football and it is plausible that more skilled (highly trained) players (such as the cohort of male footballers included in this study) may have better coordination and more efficient control over the trunk and lower extremity joints in functional movements than less conditioned players. In lower-skilled football players, such as the female players recruited, isolated muscle strength and core stability may still be predictive of performance in dynamic tasks. This may be due to comparatively less synchronized movement and possibly more reliance on a single muscle group to complete tasks like the Y-balance test. However, the lower joints ROM scores reported by the males in comparison with the females (mainly in ankle dorsiflexion and passive hip flexion) may have compromised the aforementioned advantage and would explain why both sexes showed similar Y-Balance test reached distances.

For both sexes, the regression equations generated only explained modest percentages of the performance achieved in the composite score of the Y-Balance test (23.1% [dominant leg] and 33.5% [non-dominant leg] for males and 38.2% [dominant leg] and 46.9% [non-dominant leg] for females). Comparisons with other regression models are not possible as this is the first study that has investigated the concurrent influence of a range of modifiable neuromuscular measures in the Y-Balance test performance. Future studies should consider the inclusion of other factors such as core endurance, muscle stiffness and closed chain lower extremity strength measures in the regression analysis in order to determine whether they would increase the modest percentages of explained variance reported in this study. Likewise, intervention studies should implement the measures suggested to improve unilateral dynamic balance and analyse their efficacy and impact on sport performance and injury prevention.

The current findings are limited to the participants' sport background (professional football players) so that extrapolation to other sport cohorts should be made with a certain degree of caution. Each sport modality and level of competition requires differences in technical skills, specific movements, training load and physical capacities, all of which predispose athletes to individual chronic musculo-skeletal adaptations, thus possibly developing different strategies for neuromuscular control and influencing subsequent Y-Balance test scores [6].Subsequently, elite football players demonstrate better unilateral dynamic balance capability than their non-elite peers [8,27,34] and when compared with other sporting populations [6], suggesting that the Y-Balance test may be sensitive enough to show training age and sport-related adaptation to unilateral dynamic balance. Another limitation of the current study is that there were a disproportionate number of male participants compared to female participants. However, it should be noted that the variability in the male and female scores on the Y-Balance test and measured neuromuscular parameters were similar. This observation would suggest that any Type II error that may be attributed to lower participant numbers and high levels of variability would be minimal due to the relatively normalized variance between the sexes. Isokinetic (knee) and isometric (hip) strength was tested in an open chain rather than in close chain movement. This may have resulted in the non-significant correlations observed in both males and females, due to the lack of movement specificity between open chain dynamometry and functional performance. However, the researchers felt that this was the most objective and reliable way of assessing hip and knee strength.

The current findings suggest that training interventions should be aimed at improving or maintaining unilateral dynamic balance in professional male football players and include, among other things, stretching exercises for the major muscles of the posterior chain (i.e. hamstrings, gastrocnemius, soleus) of the lower extremity. For females football players, training interventions should be focused on exercises designed to improve: a) ankle dorsiflexion and hip abduction ROMs; b) strength and mobility of the hip abductors; and c) core stability (especially in the frontal plane).

Conclusions

The main findings of the current study indicate that despite the fact that male and female professional football players show similar unilateral dynamic balance scores, different measures of neuromuscular performance appear to influence this fundamental ability. Thus, for males, those variables related to movement patterns in the sagittal plane (passive hip flexion with knee flexed and ankle dorsiflexion with knee flexed ROM measures) are important in the overall balance score obtained in the Y-Balance test. However, for females, variables related to the performance of movement patterns in the frontal plane such as core stability (medial-lateral displacements with feedback), hip abduction strength and ROM (passive hip abduction) were considered predictors of Y-Balance test reached distances.

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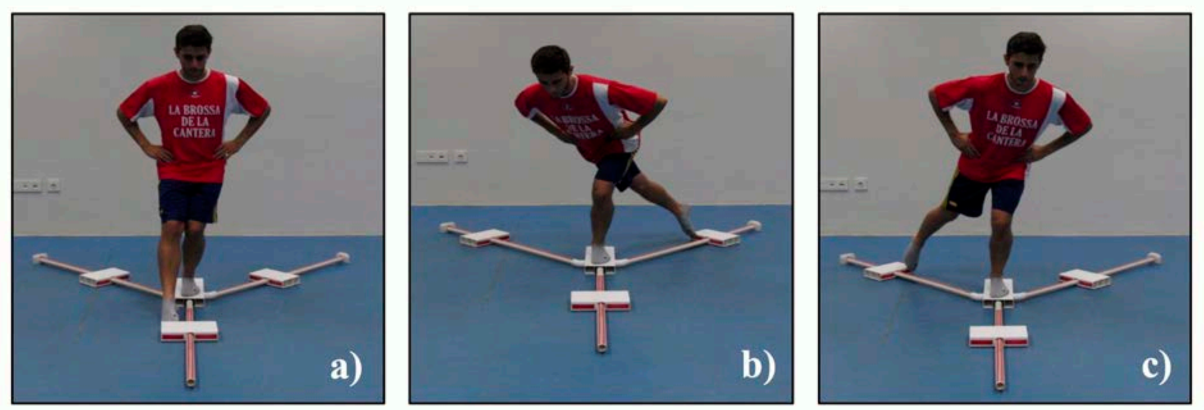
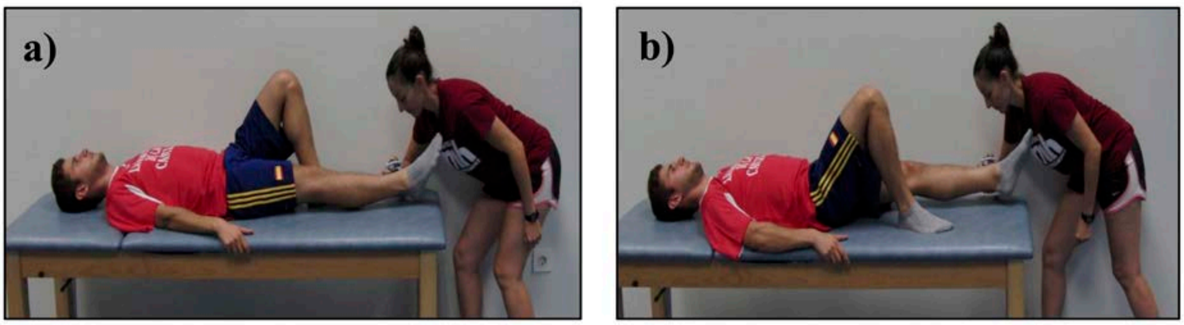
Appendixes legend

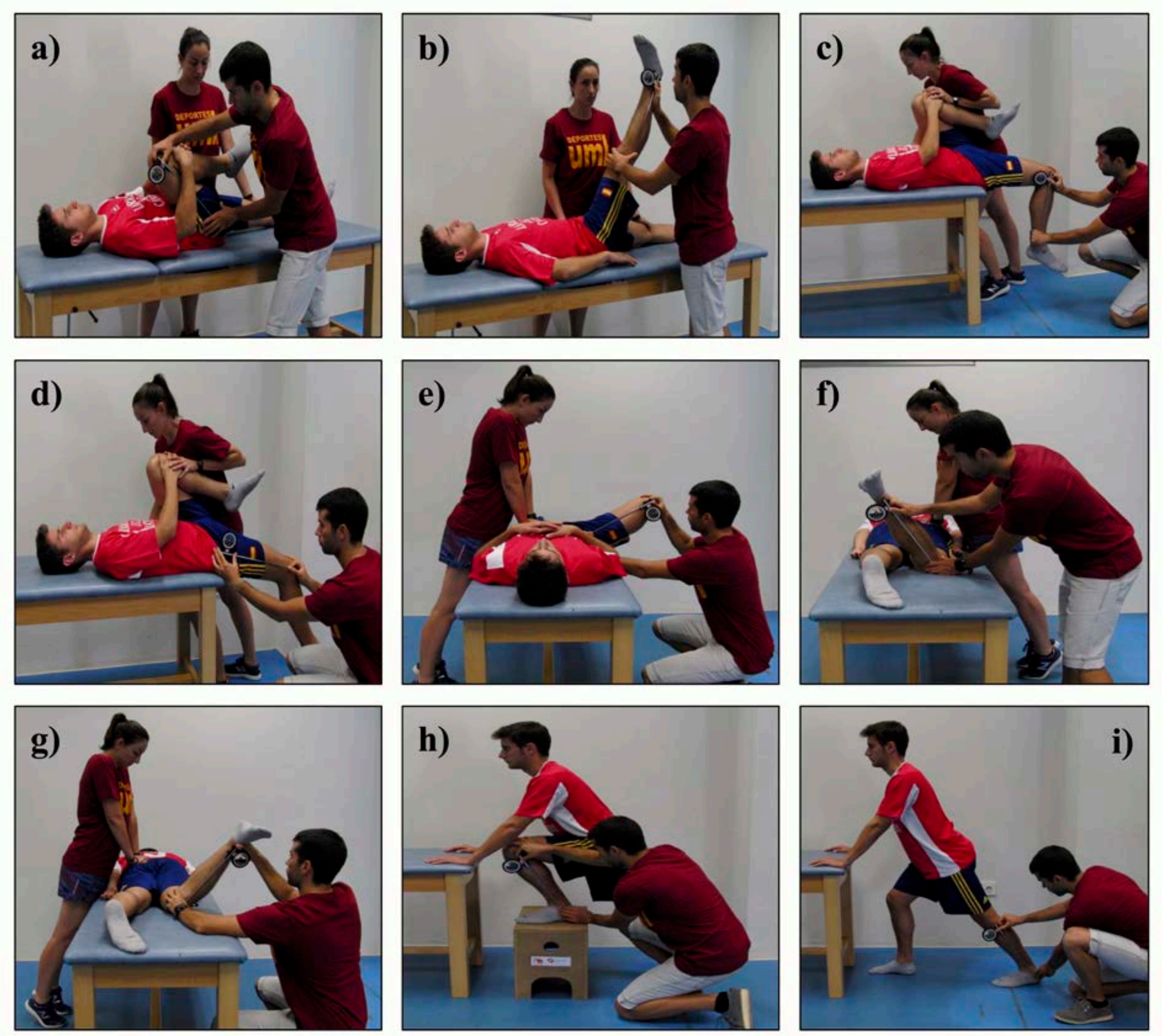
Appendix 1: Y-Balance Test™ directions; a) anterior reach direction; b) posteromedial reach direction; c) posterolateral reach direction.



Appendix 2: Isometric hip adduction (a) and abduction (b) strength assessment.

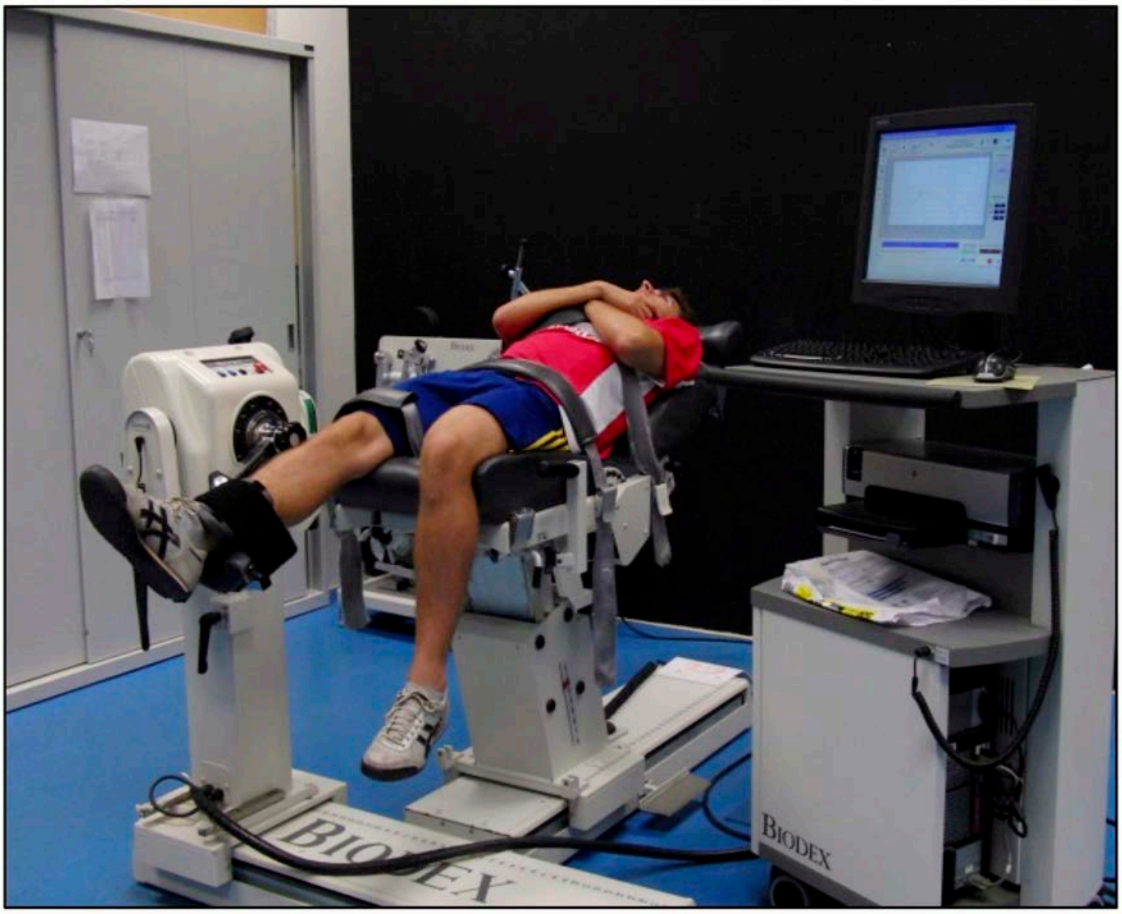


Appendix 3: Lower extremity joints ROM assessment: a) passive hip flexion with knee flexed test; b) passive hip flexion with knee extended test; c) passive knee flexion; d) passive hip extension; e) passive hip abduction; f) passive hip external rotation test; g) passive hip internal rotation test; h) ankle dorsiflexion with knee flexed test; and i) ankle dorsiflexion with knee extended test.



Appendix 4: Participant performing unstable sitting protocol. Projection providing visual feedback of participants' centre of pressure and a target point moving across a circular path.

Appendix 5: Isokinetic knee flexion and extension strength assessment.



Appendix 6: Correlations of isokinetic strength of the knee (flexion and extension), isometric strength of the hip (abduction and adduction), trunk stability and lower extremity joints range of motions measures with composite balance scores of the dominant and non-dominant leg for stance during Y-Balance test in male professional soccer players (n = 86).

Measure	**Unilateral Dynamic Balance**	
	Dominant leg	**Non-dominant leg**
*Isokinetic strength (N*m/kg)*		
Concentric KF		
▪ PT_{60}	0.163	0.016
▪ PT_{180}	0.255*	0.013
▪ PT_{240}	0.21	0.151
▪ PT_{300}	0.216	0.194
Concentric KE		
▪ PT_{60}	0.154	0.025
▪ PT_{180}	0.188	0.063
▪ PT_{240}	0.147	0.084
▪ PT_{300}	0.173	0.162
Eccentric KF		
▪ PT_{30}	0.115	0.125
▪ PT_{60}	0.115	0.152
▪ PT_{180}	0.132	0.253*
Eccentric KE		
▪ PT_{30}	0.103	0.067
▪ PT_{60}	0.258*	0.15
▪ PT_{180}	0.352**	0.210

Isometric hip strength (N/kg)		
PT_{HABD}	0.269*	0.135
PT_{HADD}	0.000	0.114
Core stability (mm)		
CS_{NF}	0.054	0.008
CS_{WF}	-0.003	-0.014
CS_{ML}	0.064	-0.024
CS_{AP}	-0.021	-0.052
CS_{CD}	0.026	-0.028
Lower extremity joints ROM (º)		
PHF_{KE}	0.012	0.053
PHF_{KF}	0.382*	0.445*
PHA	-0.035	0.172
PHER	0.021	0.028
PHIR	0.03	0.108
PHE	0.063	0.187
PKF	0.138	0.302**
ADF_{KF}	0.344**	0.429**
ADF_{KE}	0.229*	0.385**

PT: peak torque; KF: knee flexion; KE: knee extension; N: newton; m: metres; kg: kilograms; mm: millimetres; HABD: hip abduction; HADD: hip adduction; CS_{NF}: unstable sitting without feedback; CS_{WF}: unstable sitting with feedback; CS_{ML}: unstable sitting while performing medial-lateral displacements with feedback; CS_{AP}:

unstable sitting while performing anterior-posterior displacements with feedback; CS_{CD}: unstable sitting while performing circular displacements with feedback; ROM: range of motion; PHF_{KF}: passive hip flexion with knee flexed ROM; PHF_{KE}: passive hip flexion with knee extended ROM; PHA: passive hip abduction ROM; PHIR = passive hip internal rotation ROM; PHER: passive hip external rotation ROM; PHE: passive hip extension ROM; PKF: passive knee flexion ROM; ADF_{KE}: ankle dorsi-flexion with knee extended ROM; ADF_{KF}: Ankle dorsi-flexion with knee flexed ROM; *: $p < 0.05$; **: $p < 0.01$

Appendix 7: Correlations of isokinetic strength of the knee (flexion and extension), isometric strength of the hip (abduction and adduction), trunk stability and lower extremity joints range of motions measures with composite balance scores of the dominant and non-dominant leg for stance during Y-Balance test in female professional soccer players (n = 44).

Measure	**Unilateral Dynamic Balance**	
	Dominant leg	**Non-dominant leg**
*Isokinetic strength (N*m/kg)*		
Concentric KF		
▪ PT_{60}	0.086	0.016
▪ PT_{180}	0.076	0.013
▪ PT_{240}	0.153	0.151
▪ PT_{300}	-0.214	0.194
Concentric KE		
▪ PT_{60}	0.379*	0.025
▪ PT_{180}	0.359	0.063
▪ PT_{240}	0.320	0.084
▪ PT_{300}	0.289	0.162
Eccentric KF		
▪ PT_{30}	0.187	0.163
▪ PT_{60}	0.180	0.220
▪ PT_{180}	0.204	0.415*
Eccentric KE		
▪ PT_{30}	-0.021	0.103
▪ PT_{60}	-0.042	0.248
▪ PT_{180}	0.055	0.275

Isometric hip strength (N/kg)		
PT_{HABD}	0.415**	0.529**
PT_{HADD}	0.322*	0.411**
Core stability (mm)		
CSNF	-0.246	-0.386**
CSWF	-0.257	-0.317*
CSML	-0.446**	-0.551**
CSAP	-0.292	-0.423**
CSCD	-0.289	-0.478**
Lower extremity joints ROM (º)		
PHF_{KE}	0.295	0.184
PHF_{KF}	-0.179	-0.212
PHA	0.469**	0.071
PHER	-0.143	-0.129
PHIR	0.297	0.286
PHE	0.399*	0.231
PKF	0.140	0.348*
ADF_{KF}	0.340	0.270
ADF_{KE}	0.284	0.090

PT: peak torque; KF: knee flexion; KE: knee extension; N: newton; m: metres; kg: kilograms; mm: millimetres; HABD: hip abduction; HADD: hip adduction; CS_{NF}: unstable sitting without feedback; CS_{WF}: unstable sitting with feedback; CS_{ML}: unstable sitting while performing medial-lateral displacements with feedback; CS_{AP}:

unstable sitting while performing anterior-posterior displacements with feedback; CS_{CD}: unstable sitting while performing circular displacements with feedback; ROM: range of motion; PHF_{KF}: passive hip flexion with knee flexed ROM; PHF_{KE}: passive hip flexion with knee extended ROM; PHA: passive hip abduction ROM; PHIR = passive hip internal rotation ROM; PHER: passive hip external rotation ROM; PHE: passive hip extension ROM; PKF: passive knee flexion ROM; ADF_{KE}: ankle dorsi-flexion with knee extended ROM; ADF_{KF}: Ankle dorsi-flexion with knee flexed ROM; *: $p < 0.05$; **: $p < 0.01$